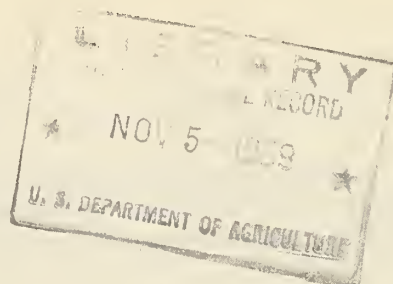


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Laboratory tests
of REFRIGERATOR CARS
for **PERISHABLE FOODS**



Marketing Research Report No. 365

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Marketing Research Division

PREFACE

This study is part of a broad program of research to improve the design and performance of transportation equipment used in the movement of agricultural products, as a means of improving and expanding the marketing of farm products.

Little precise information has been available heretofore regarding the efficiency of refrigerated railroad cars in terms of their heat transfer performance. This study has produced comparative information on certain types of cars and their refrigerating units to assist in the improvement of design and to reduce deterioration and spoilage of perishable foods in transit to market.

The General American Transportation Corporation and the Pacific Fruit Express Company cooperated in the tests.

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Washington, D. C.

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LABORATORY TESTS OF REFRIGERATOR CARS FOR PERISHABLE FOODS

By Ronald W. Penney and Robert F. Guilfooy
Transportation and Facilities Branch
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SUMMARY

The performances of several types of refrigerator cars were compared in a laboratory in which the ambient temperature (the temperature outside the cars) could be controlled. Two different tests were made on each car. In one test, the heat transmission rate, or U-factor, for the car body was determined by the reverse heat flow method. The U-factor is expressed in the number of British thermal units (B.t.u.) which will migrate through the car walls during 1 hour for each degree of temperature difference between inside and outside. In the other test, the ability of the mechanical refrigerating unit to lower the inside air temperature to the desired level was determined.

Test results showed a wide variation in performance among the cars. The U-factor of four 40-foot mechanical cars varied from 85.5 to 126 B.t.u. Two 50-foot mechanical cars had U-factors of 122 and 153.5, even though they were supposed to be of identical construction. A 40-foot ice car had a U-factor of 151.0.

Three of the 40-foot mechanical cars, designed for 0° F. service, failed to reach that temperature by 3° to 7°. One of the 50-foot mechanical cars reached 0° and had an estimated additional capacity sufficient to cool the car down to -10°. A 40-foot mechanical car designed for 35° interior temperature at 90° ambient was able to reach 35° interior without difficulty.

From the results of a reverse heat flow test and the known performance of the refrigerating unit, a method is given to estimate the time required to precool a car from ambient temperature to a desired level before loading. A long pulldown time indicates the need for a car body with a lower heat transmission rate or a refrigerating unit of larger capacity, or both. If the specifications of the car require that it be capable of reducing interior temperature from maximum ambient to a specified precool temperature before loading, the method developed in this study will enable the selection of a refrigerating unit and cooling coil of sufficient capacity to assure proper performance.

This study indicates that an industrywide standard method of rating refrigerator car performance would provide better means for analyzing experimental structural innovations and for exchange of information within the industry. This should lead to better quality control in refrigerator car construction and, in turn, to increased efficiency of operation and better control in the protection of perishable foods during movement to market.

INTRODUCTION

The consumption of perishable agricultural products in the United States has grown tremendously since the beginning of this century. Refrigerated shipments of meats, dairy products, and fruits and vegetables enable consumers to enjoy these commodities throughout the year regardless of where they live or how far they are from the growing area. Urban dwellers no longer are dependent upon the immediately surrounding farm areas for their perishable foods. These factors, of course, also broaden outlets for farm products.

Ordinary ice is still the most widely used refrigerant in railroad cars. However, the years immediately following World War II brought in the mechanical refrigerator car. By 1953 there were about 450 of these cars either in service or under construction. This number has increased significantly, and in 1959 approximately 4,000 of this type of car were in service. Mechanically refrigerated cars are, generally, intended for "all-purpose" use, providing any desired temperature from below 0° to plus 70° F.

There are many different types of car body designs, as well as several different refrigerating units manufactured for use with the cars. This study was designed to obtain comparative information regarding the insulating efficiency, or heat transmission rate, of several typical cars. At the same time, some typical refrigerating units were tested to determine their ability to maintain the desired temperatures.

DESCRIPTION OF CARS TESTED

Seven cars were tested, including four 40-foot-long mechanically refrigerated cars, one 40-foot water ice car, and two 50-foot mechanically refrigerated cars. Following are descriptions of the seven cars and their refrigerating units:

Car A

Body: 40-foot nominal length; capacity 75,000 pounds, 1,714 cubic feet; length, outside 43 feet 5 inches, inside 34 feet 4 inches; height, outside 12 feet 11 inches, inside 6 feet 7 inches; width, outside 9 feet 10 inches, inside 7 feet 7 inches; meat rails and floor racks; insulation of rigid foam, 7 inches in floor, 6 inches in walls, end, and roof. Built November 1950.

Refrigeration unit 1: Power, 2-cylinder engine using propane fuel, bore $3\frac{1}{2}$ inches, stroke 3 inches, 50 cubic inches displacement, 8.5 to 13 horsepower at 2700 RPM, air-cooled, oil capacity 6 quarts, 12-volt starter and ignition system, speed at full throttle 2100 RPM, $\frac{1}{2}$ throttle 1100 RPM. Compressor, 2-cylinder with speed = 0.75 X engine speed. Engine and compressor operation continuous at either high or low speed. Unit heats car by means of hot gas. Thermostat range -10° to +70°. Air blast from unit is directed under the

floor racks, thence up side and end wall flues and back to the return grill.

Refrigeration unit 2: Same as unit 1 except a revised and later model.

Car B

Body: 40-foot nominal length; capacity 80,000 pounds, 2,113 cubic feet; length, outside 43 feet 8 3/4 inches, inside 35 feet 4 inches; height, outside 13 feet 3 9/16 inches, inside 7 feet 3 inches; width, outside 9 feet 9 inches, inside 8 feet 3 inches; floor racks, sidewall flues, and diffusers in ceiling; insulation, 6 inches rigid foam in floor, 3 inches glass fiber and 3 inches laminated panel 1/ in walls, 4 inches and 2 inches of glass fiber and 2 inches of laminated panel in roof. Built September 1957.

Refrigeration unit: Power, 2-cylinder diesel engine, bore 3 1/2 inches, stroke 3 inches, 92.75 cubic inches displacement, 18 horsepower at 1,800 RPM, air cooled, 12-volt starter and ignition system; generator 12.5 KW, 60-cycle, 3-phase; compressor 1,750 RPM. Air blast from unit is directed into a false ceiling and thence down through diffusers in the ceiling and down side and end wall flues, returning under the floor racks to the unit.

Car C

Body: 40-foot nominal length; capacity 80,000 pounds, 2,380 cubic feet; length, outside 42 feet 8 3/4 inches, inside 35 feet 3 inches; height, outside 14 feet 0 inches, inside 8 feet 2 inches; width, outside 9 feet 6 inches, inside 8 feet 3 inches; floor racks, sidewall flues, and diffusers in ceiling; insulation, 2-inch and 4-inch layer of rigid foam in floor, 3 inches glass fiber and 3 inches of laminated panel in walls, 4 inches glass fiber and 2 inches mineral wool and 2 1/2 inches laminated panel in roof. Outside skin, welded construction. Built September 1958.

Refrigeration unit: Power, 2-cylinder diesel engine-generator, bore 4 inches, stroke 4 inches, 100 cubic inches displacement, 18 horsepower at 1,800 RPM, water cooled, oil capacity 11 quarts, 12.5 KW generator output, 12-volt starting system; compressor, 2 each, tandem mounted, total of 10 cylinders, primary Refrigerant 12, secondary refrigerant trichlorethylene; unit heats and cools. Thermostat range, -10° to +70°. Air blast from unit is directed into a false ceiling and thence down through diffusers in the ceiling and down side and end wall flues, returning under the floor racks to the unit.

Car D

Body: Same as car C, except outside skin is riveted construction. Built September 1958.

1/ Laminated panel consists of alternate layers of corrugated aluminum sheets and glass fiber.

Refrigeration unit: Power, 2-cylinder diesel engine-generator, bore 4 inches, stroke 4 inches, 100 cubic inches displacement, 18-horsepower at 1,800 RPM, water cooled, oil capacity 11 quarts, 12.5 KW generator output, 12-volt starting system; compressor, 3-cylinder using Refrigerant 12. Air blast from unit is directed into a false ceiling and thence down through diffusers in the ceiling and down side and end wall flues, returning under the floor racks to the unit.

Car E

Body: 40-foot nominal length; capacity 76,000 pounds, 2,022 cubic feet; length, outside 42 feet 8 3/4 inches, inside 33 feet 2 3/4 inches; height, outside 12 feet 9 15/32 inches, inside 7 feet 4 1/2 inches; width, outside 9 feet 5 7/8 inches, inside 8 feet 3 inches; floor racks and sidewall flues; insulation, 7 inches rigid foam in floor, 3 inches glass fiber and 3 inches laminated panel in walls, 3 inches glass fiber and 2 inches mineral wool and 2 1/2 inches laminated panel and 3 inches glass fiber in roof. Built April 1957.

Refrigeration: Conventional stage-ice bunker at each end of car with electric-driven air circulating fans at top of the bunkers.

Car F

Body: 50-foot nominal length; capacity 93,000 pounds, 3,026 cubic feet; length, outside 52 feet 8 3/4 inches, inside 44 feet 6 inches; height, outside 14 feet 2 inches, inside 8 feet 0 inches; width, outside 9 feet 10 inches, inside 8 feet 6 inches; floor racks, sidewall flues, diffusers in ceiling; insulation, 6 inches rigid foam in floor, 3 inches fiber glass and 3 inches laminated panel in walls, two 2-inch layers mineral wool and 2 inches laminated panel in roof. Built July 1958.

Refrigeration unit: Power, 2-cylinder diesel engine, bore 4.25 inches, stroke 5 inches, 141.9 cubic inches displacement, water cooled; generator, 220 volt, 49 ampere, 3 phase, 1,200 RPM; compressor, 4 cylinder, 10-horsepower, 1,750 RPM, with 2-horsepower fan motor.

Car G

Body: Same as car F.

Refrigeration unit: Same as in car F.

One of the 40-foot cars and one of the 50-foot cars tested are shown in figures 1 and 2, respectively. The door of the refrigerating compartment on each car is in the open position showing a portion of the refrigeration unit. Figure 3 is a view inside the refrigeration compartment of one of the cars, showing the diesel engine, the electric power generator, and the condensing fan and motor. A view of the evaporator, or cooling coils, with the cover panel removed, in one of the cars is shown in figure 4. Car B, the only car used in the test which had a welded instead of conventional riveted outside skin, is shown in figure 5.



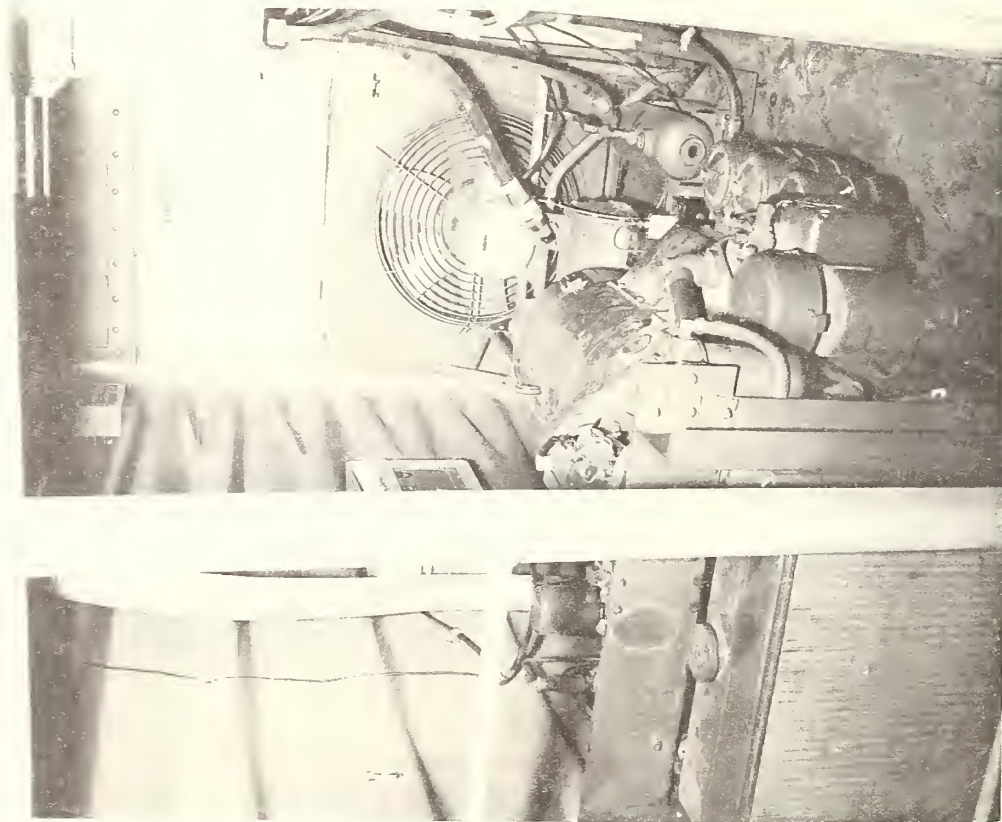
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Figure 1.--One of the 40-foot cars used in the tests, showing refrigerating compartment door in open position.



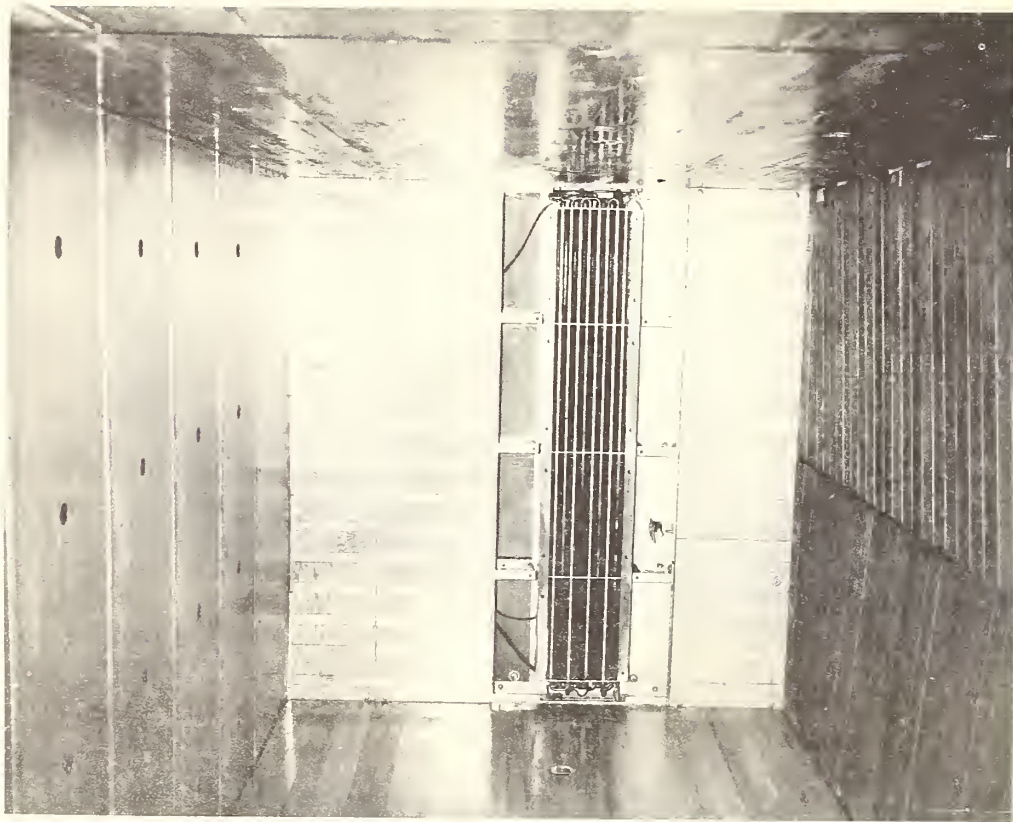
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Figure 2.--One of the 50-foot cars used in the tests, showing refrigerating compartment door in open position.



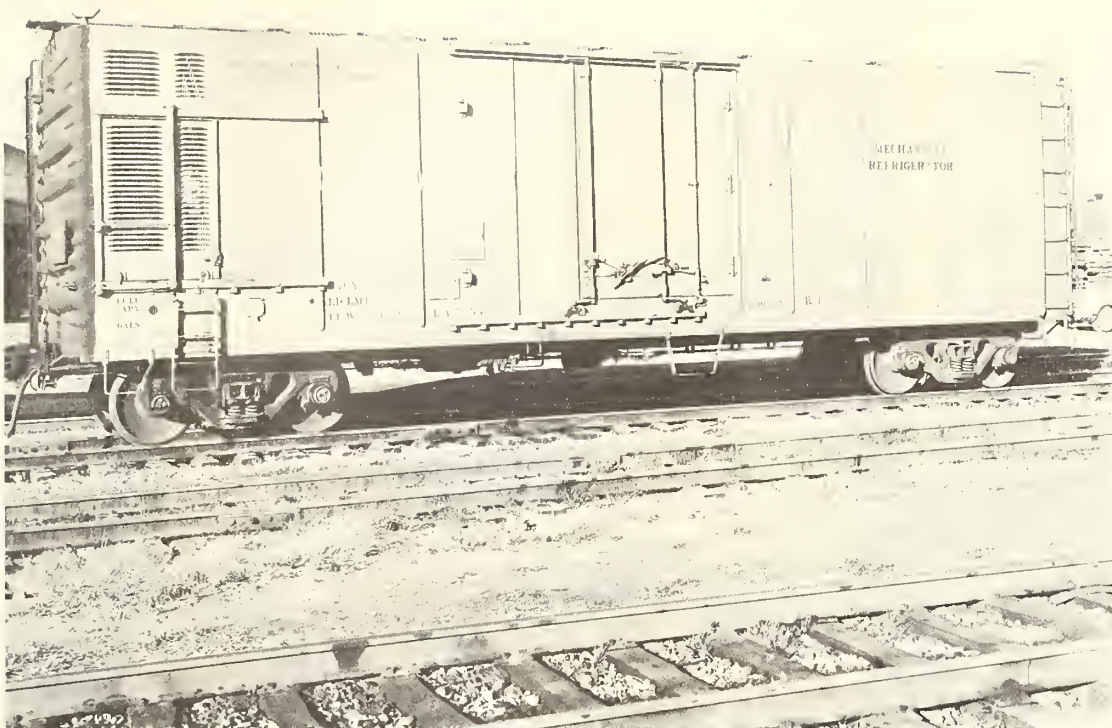
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Figure 3.-- View inside one of the refrigerating compartments, showing the diesel engine, electric power generator, and condensing fan and motor.



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Figure 4.-- The cooling coils with cover panel removed in one of the cars.



BN-7608

Figure 5.-- Car B, the only car tested which had a welded instead of conventional riveted outside skin.

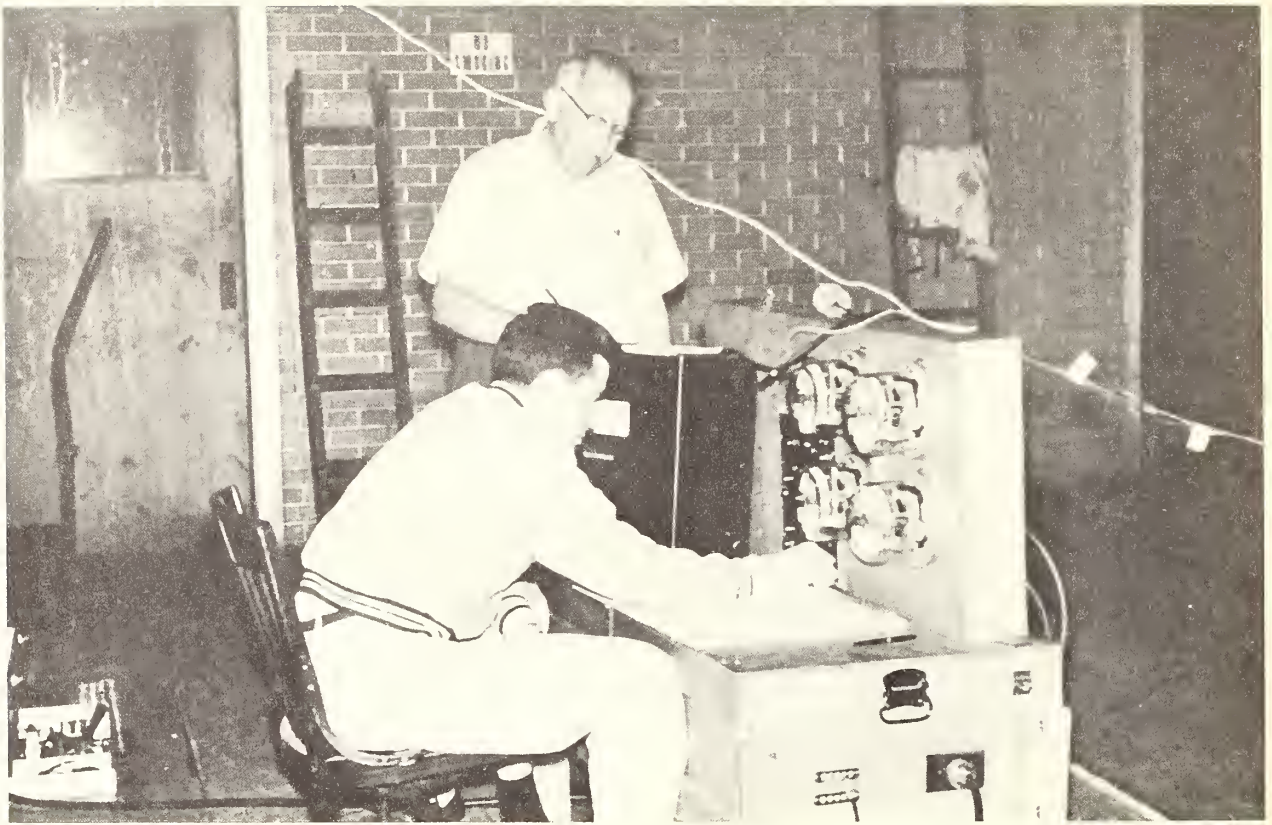
TEST PROCEDURE

Tests were conducted in a heated and insulated building 60 feet long by 30 feet wide by 25 feet high, in which the air temperature could be thermostatically controlled. A 10-kw. heater with integral fan and two separate circulating fans were placed inside the car. Power input and temperature readings at points inside and outside the car were taken at hourly intervals by means of the instrument panel shown in figure 6. The electrical hookup for power input and measurement is shown in figure 7.

Temperatures were measured with copper-constantan thermocouples and a continuous balance potentiometer. Figure 8 shows a cross section of one of the cars and points at which temperatures were taken. Temperatures were taken at the same location in each car except where there was a difference in location of the air inlet and outlet of the refrigerating unit.

Body U-Factor

The body heat transmission rate, or U-factor, is expressed in the number of British thermal units (B.t.u.) which migrate through the car walls during 1 hour for each degree of temperature difference between inside and outside.



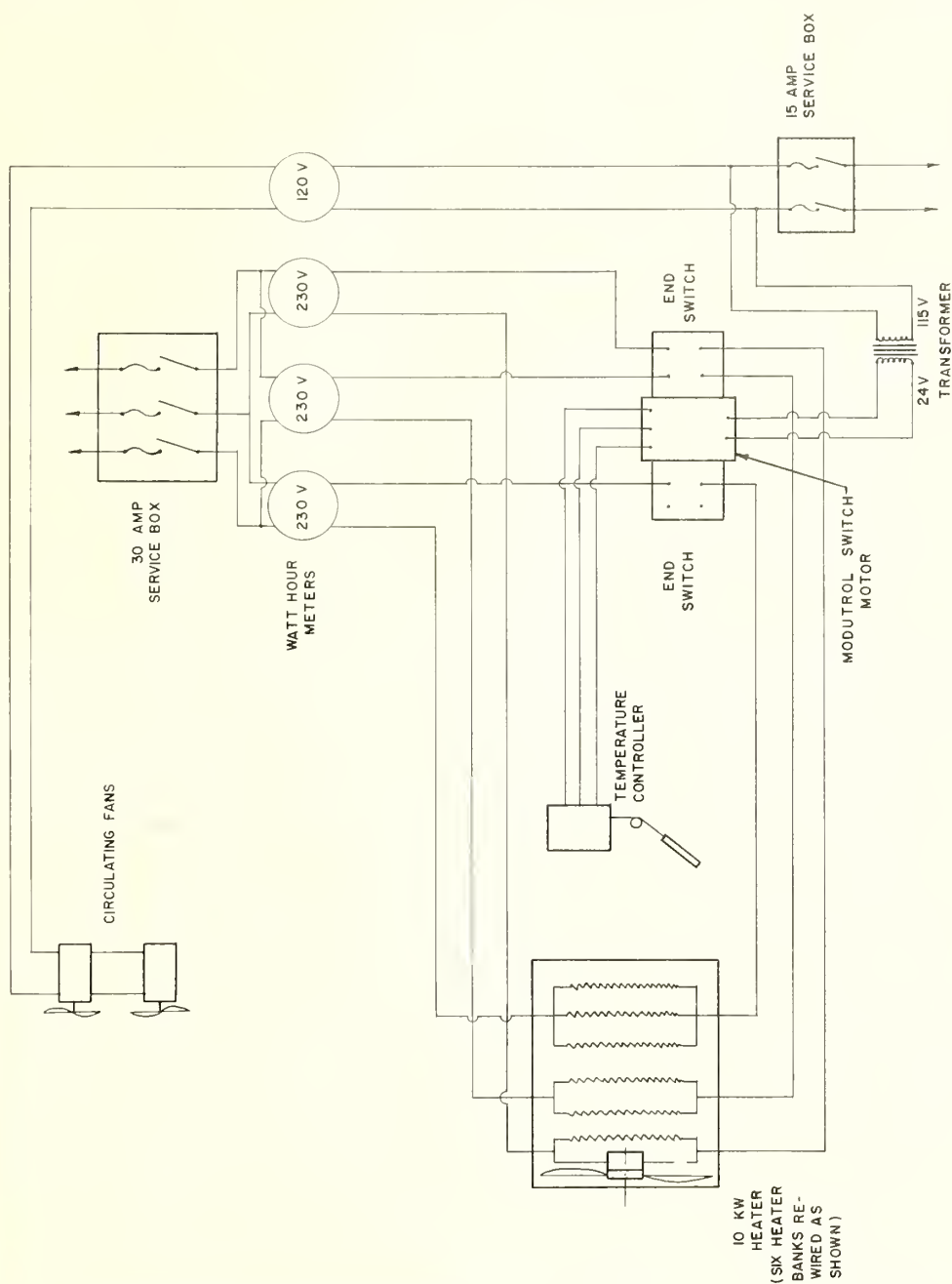
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Figure 6.-- Instrument panel used to obtain hourly electrical power input and temperature readings during the tests.

The U-factor was determined by the reverse heat flow method, in which the car interior is heated instead of refrigerated. In this test the thermostat inside the car, which controlled the heater, was set at 130° F. and the ambient room temperature thermostat was set at 75°. The test was continued at these conditions until such time as the heat input, and therefore the heat flow through the car walls, became essentially steady. The U-factor for each car was determined by taking the average of the U-factors calculated for 3 or more consecutive hours of this steady heat flow.

Refrigerating Unit Capacity

In this test the ambient, or room, temperature and the interior temperature in the car were set according to the conditions at which the car was designed to operate. For car A, ambient temperature was set at 90° F. and car interior at 35°. For the remaining cars, except water-ice car E, which was not tested, ambient temperature was maintained at 100° and the car interior controlled at 0°. For those cars that were unable to reach 0°, the ambient temperature was actually lowered several degrees below 100° in an effort to reach 0° inside. The heater thermostat in each car test was set to operate at the same temperature as the refrigeration unit setting. The purpose

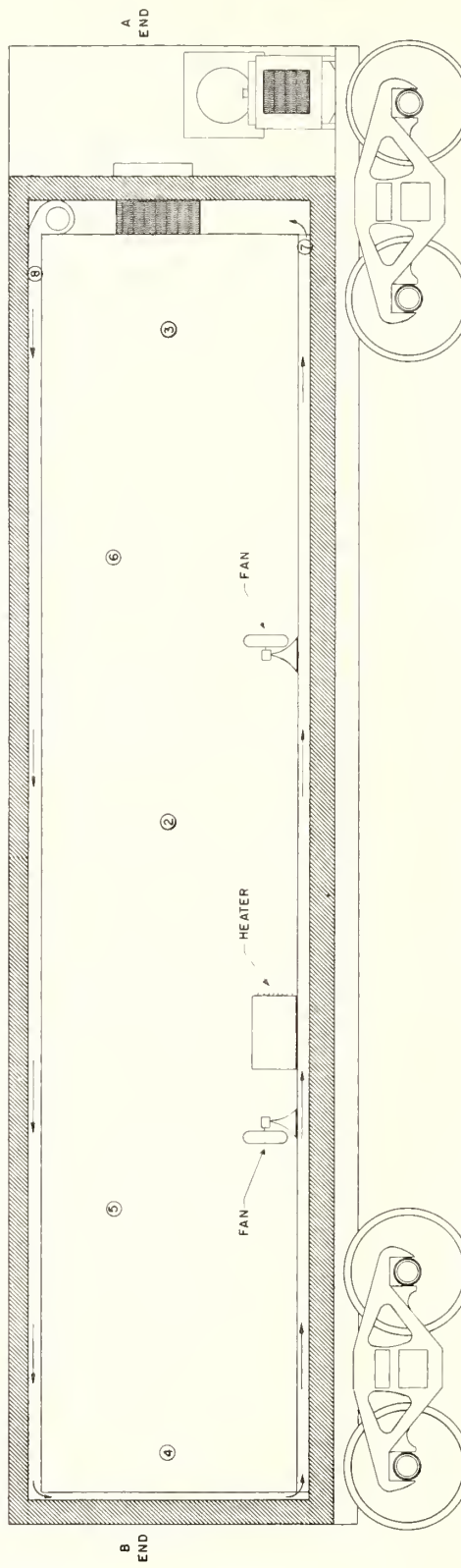


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Figure 7.-- Schematic diagram showing electrical connections used to measure power input to heaters inside the car.



LEGEND

- 1 ICE BATH (NOT SHOWN, USED AS CHECK TEMPERATURE)
- 2 DOORWAY, CENTER OF CAR
- 3 "A" END, CENTER OF CAR
- 4 "B" END, CENTER OF CAR
- 5 AMBIENT LEFT SIDE, 6" FROM OUTSIDE SURFACE
- 6 AMBIENT RIGHT SIDE, 6" FROM OUTSIDE SURFACE
- 7 AIR RETURN
- B AIR BLAST

Figure 8.-- Cross section view of one of the cars showing general construction, heater and fan arrangement, and locations at which temperatures were taken.

of this procedure was to have the heater operate in opposition to the refrigeration unit after the desired car interior temperature had been reached. The capacity of the refrigerating unit is the sum of the car body heat transmission rate previously determined plus the rate of electrical power input to the heaters inside the car. The test was continued until the heat input to the car became essentially steady. The refrigerating unit capacity was calculated from the data of 3 or more consecutive hours of essentially steady conditions.

The volume of air movement in the car was obtained by measuring the air velocity with an air meter at either the inlet or outlet grill of the refrigerating unit. Fuel consumption was determined either from weigh scale readings or from gage readings of the fuel tank on each car, taken at the start and at the finish of each test.

Two refrigeration tests were made on car A, the first with refrigeration unit 1. Refrigeration unit 1 was then replaced by refrigeration unit 2, after which the second test was made. Single refrigeration tests were made on cars B, D, and F, and two tests were made on car C.

TEST RESULTS

Performance Summary

A summary of test results for the seven cars is shown in table 1. The body U-factors of the four 40-foot mechanical cars (A, B, C, D) varied from 85.5 to 126.0 B.t.u. Car B, with the best figure of 85.5 had a welded outside skin, which may be of significance. The two 50-foot mechanical cars (F, G), which were supposed to be of identical construction, were found to have different U-factors of 153.5 and 122.0. The 40-foot ice car (E) had a U-factor of 151.0.

None of the refrigerating units in the three 40-foot mechanical cars (B, C, D) designed for 0° was able to reach that temperature at 100° ambient, failing by about 3° to 7°. For those cars that were unable to reach 0°, the ambient temperature was actually lowered several degrees below 100° in an effort to reach 0° inside. The 50-foot mechanical car (F) reached 0° inside temperature with refrigerating capacity to spare. It is estimated that the refrigerating unit in car F could have lowered the inside temperature to about -10°. The 40-foot mechanical car (A) designed for 35° inside at 90° ambient was able to reach the desired inside temperature.

Calculation of Body U-Factor

Figure 9 is a graph of the body heat transmission data obtained for car A. The graph for car A is typical of the data for the seven car bodies, A through G, and for that reason no other graphs are shown.

Table 1.-- Summary of refrigeration test results obtained for seven cars

Car	Body		Refrigerating Unit										Remarks	
	Nominal Length	"U" Factor 1/	Design Ambient : air temp.	Design inside : air temp.	Attained inside : air temp.	Refr. unit : capacity 2/	B.t.u.	°F.	°F.	Cu.ft./min.	Gals./hr.	Fuel consumption		Engine Speed
	Ft.	B.t.u.	°F.	°F.	°F.								RPM	
A	40	93.6	90	35	35	9,978	1,505	.90	1,925	High speed)	Refr. unit #1		1,925	
A	---	---	90	35	35	7,334	892	.40	4/785	Low speed)			4/785	
A	---	---	90	35	35	15,460	---	.97	2,220	High speed)	Refr. unit #2		2,220	
A	---	---	90	35	35	9,710	---	.45	4/1,150	Low speed)			4/1,150	
B	40	85.5	100	0	+4.2	3/	3/	.47	---		Condensor developed leak and refrigeration test was stopped after 47 hrs.		---	
C	40	106.0	100	0	+2.7	3/	3/	1.18	---		First refrigeration test. Unable to reach 0° inside car. Test stopped after 37 hours.		---	
C	---	---	100	0	+7.0	3/	3/	.96	---		Second refrigeration test, blowers replaced. Unable to reach 0° inside car. Test stopped after 69 hours.		---	
D	40	126.0	100	0	+6.8	3/	3/	.87	---		Unable to reach 0° F. inside car. Test stopped after 30 hours.		---	
E	40	151.0	Ice car -- no refrigeration test made										---	
F	50	153.5	100	0	0	23,010	4,100 @ 28.5°F.	1.10	---				---	
G	50	122.0	---	---	---	---	---	---	---		Refrigeration unit same as in car F and therefore not tested.		---	

1/ B.t.u. per hour per °F. temperature difference between inside and outside of car.

2/ B.t.u. per hour.

3/ No values obtained since refrigeration unit did not reach 0° F.

4/ Engine and compressor direct connected.

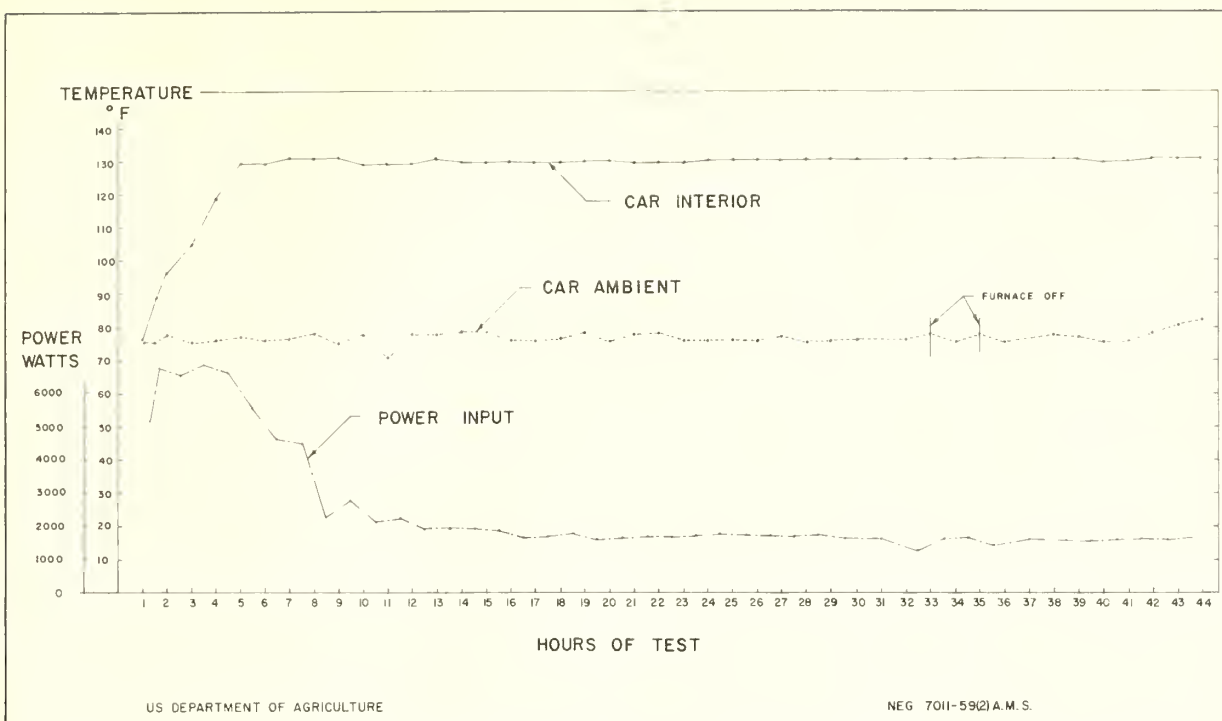


Figure 9.-- Graph of body heat transmission data obtained for car A.

The U-factor for each car was calculated from the body heat transmission data. ^{2/} The calculations for car A are shown in the following example, all other car U-factor being calculated in a similar manner.

The heat input to car A (see fig. 9) became essentially steady at about the 32nd hour of the test. The U-factor for the period from the 32nd to the 33rd hour was determined as follows:

$$\begin{aligned}
 &\text{Ambient temperature, average} = 76.6^{\circ} \text{ F.} \\
 &\text{Car inside temperature, average} = 130.85^{\circ} \\
 &\Delta T, \text{ inside to ambient} = 130.85 - 76.6 = 54.25^{\circ} \\
 &\text{Power input} = 1510 \text{ watt-hours} \\
 &\text{B.t.u.} = \text{watt-hours} \times 3.415 \\
 &\text{Heat input} = \frac{1510 \times 3.415}{1} = 5156 \text{ B.t.u./hr.} \\
 &U = \frac{5156}{1 \times 54.25} = 95.0 \text{ B.t.u./hr.} \times ^{\circ}\text{F.}
 \end{aligned}$$

The U-factor for each hour between the 33rd and the 39th hour was determined in the same manner. The average of the U-factors from the 32nd to the 39th hour was found to be 93.6.

^{2/} Detailed data available upon request from Transportation and Facilities Branch, Agricultural Marketing Service.

Calculation of Refrigeration Unit Capacity

Figure 10 is a graph of the data obtained for refrigeration unit 1 in car A. The graphs for the refrigeration units in cars A(1), A(2), B, C(1), C(2), D, and F are similar and for that reason only one graph is shown. ^{3/} No refrigerating capacity was calculated for cars B, C, or D, since these units did not reach the desired inside car temperature. The calculations for refrigeration unit 1 in car A for high speed are shown in the following example, the refrigeration unit capacity for car F being calculated in a similar manner.

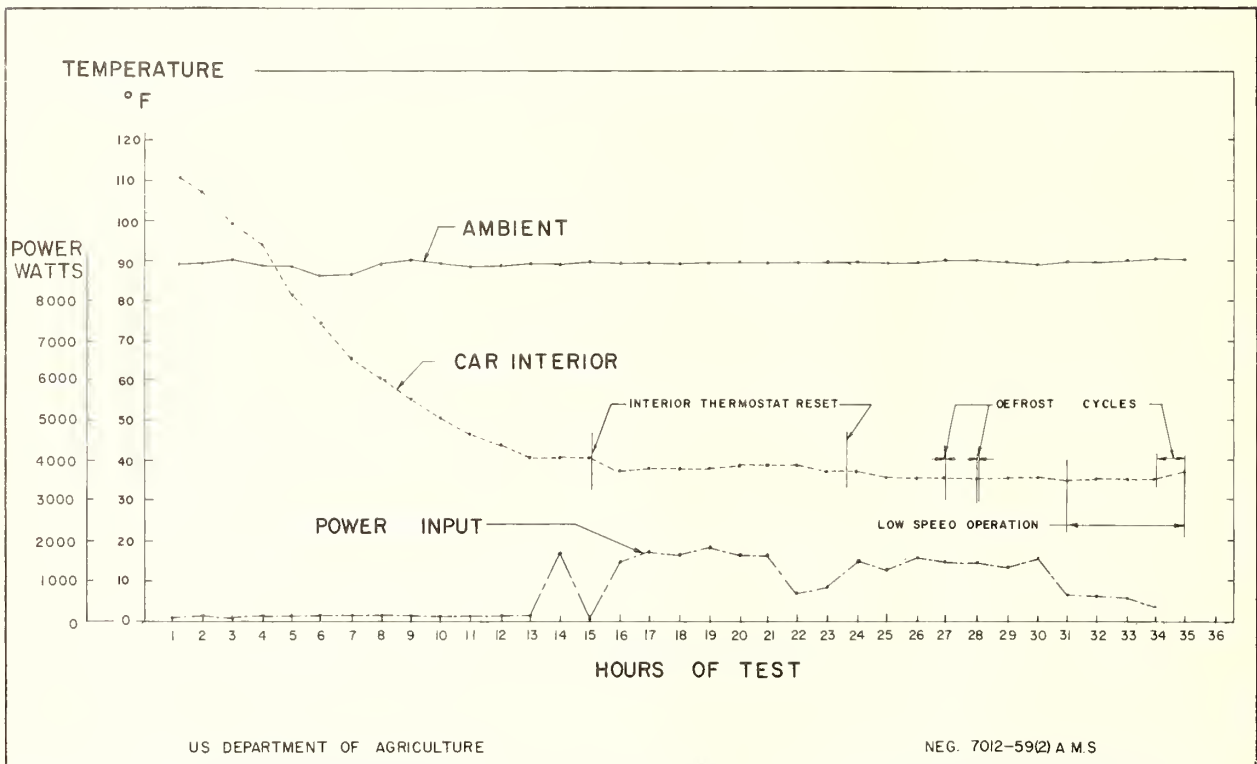


Figure 10.-- Graph of test data obtained for refrigeration unit No. 1 in car A.

The test conditions (high speed) became essentially steady at about the 24th hour of the test. The capacity for the period from the 24th to the 25th hour was determined as follows:

Ambient temperature, average = 88.98° F.

Car inside temperature, average = 34.8°

ΔT , ambient to inside = 88.98 - 34.8 = 54.2°

Power input = 1,230 watt-hours

Heat input = $\frac{1,230 \times 3.415}{1} = 4,200$ B.t.u./hr.

U (previously determined) = 93.6

Body heat transmission = $U \times \Delta T = 93.6 \times 54.2 = 5070$ B.t.u./hr.

Refrigeration unit capacity = 4200 + 5070 = 9270 B.t.u./hr.

^{3/} See footnote 2 on page 15.

The refrigeration capacity for each hour between the 25th and the 28½th hour was determined in the same manner. The average of the capacities from the 24th to the 28½th hour was found to be 9,978.

The rate of air flow through the refrigeration units was determined for those cars, A and F, which were able to reach the desired inside temperature. Calculations for car A are shown in the following example, the air flow for car F being calculated in a similar manner.

High speed (1,925 RPM):
 Outlet area.....1.075 square feet
 Air temperature.....36.2° F.
 Air velocity (average of 5 readings).....1,400 ft./minute
 Air flow = 1.075 x 1,400 = 1,505 cfm

The fuel tank for car A was set on a weigh scale and the weight of fuel in the tank at the start and at the finish of the test run was obtained. From these data, the fuel consumption per hour was calculated. For the other cars the gage reading on the car fuel tank was noted at the start and at the end of the test run, the hourly fuel consumption being calculated from these data.

Because the fuel gages on these cars were not calibrated, the fuel consumption data in table 1 should be considered as approximate.

Predicting Car Performance

Analysis of the data and graphs of these tests indicates that it is possible to predict the number of hours required for a refrigeration unit to pull-down, or precool, the car interior to a given temperature. The following paragraphs illustrate the manner in which the pulldown time can be determined.

The heat transmission rate, or U-factor, of the car body can be determined by the reverse heat flow method described previously in this report. The U-factor multiplied by temperature differential between inside and outside the car will give the hourly heat flow into the car which must be removed by the refrigerating unit. In addition, the refrigerating unit must have enough capacity to remove blower heat and to lower the thermal mass temperature of the car within a reasonable time during precooling. The effect of thermal mass when precooling a car is due to changing the temperature of the car structure, insulation, etc.

Assume, for example, a car standing in an ambient temperature of 85° F. for a period of time so that the entire mass of the car is at a temperature of 85°. We may show this condition as figure 11(a) where temperature outside the structure and temperature inside are both at 85°. Point A is the mean wall temperature (MWT) between inside and outside, and equals $\frac{85 + 85}{2} = 85^\circ$.

If the refrigeration thermostat is set at 0° and the car is cooled until the thermostat is satisfied, we have the condition shown in figure 11(b).

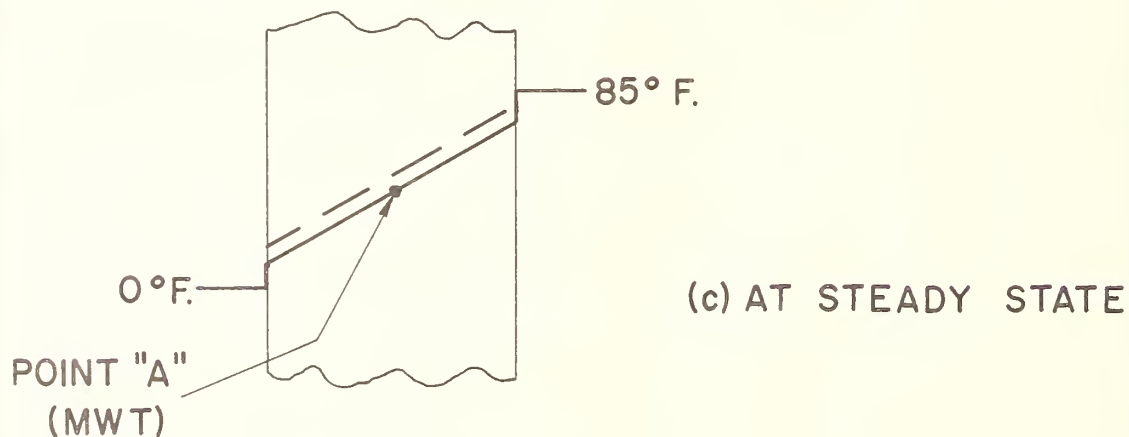
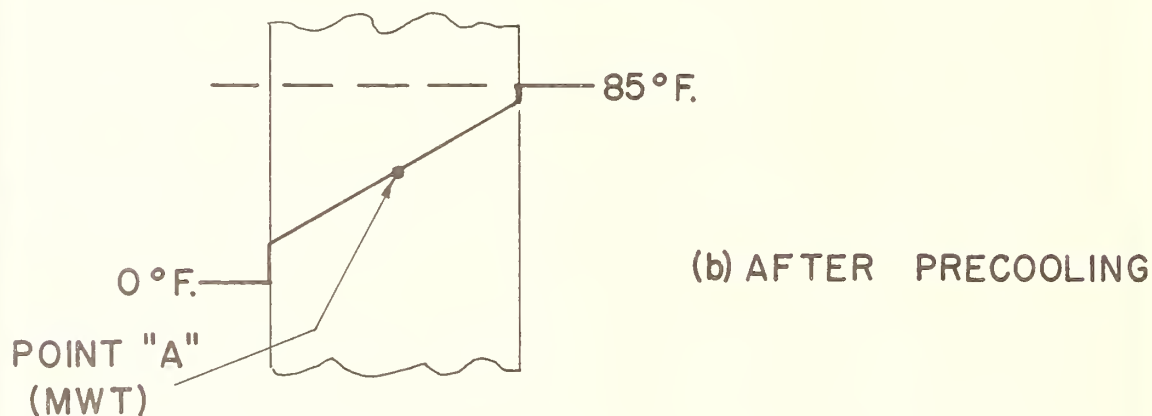
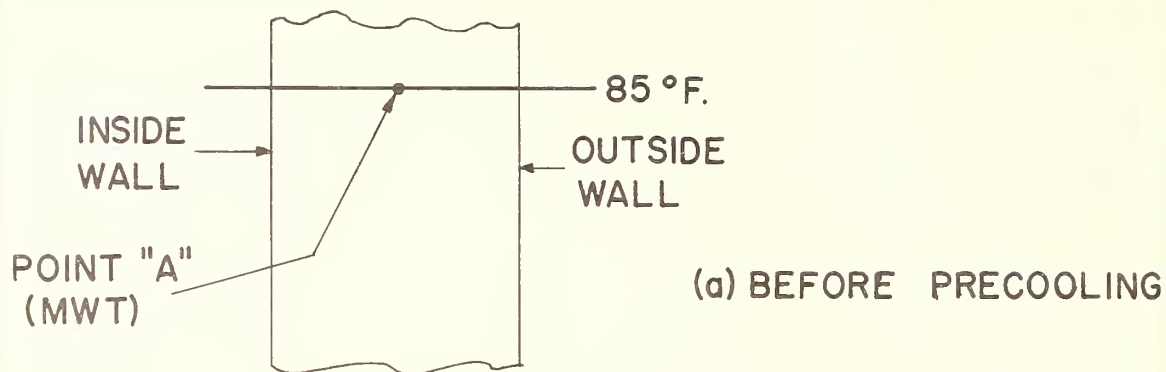


Figure 11.-- Changes in mean wall temperature (MWT) when cooling the inside of a car.

Note that while there exists an inside temperature of 0°, the inside wall temperature is above 0° due to thermal lag. A condition of steady state between zero interior and 85° ambient does not exist until a condition shown in figure 11(c) is reached. The MWT, point A, has dropped between figures 11(b) and 11(c). The MWT at figure 11(c) is now approximately $\frac{0 + 85}{2} = 42.5^\circ$.

2

The heat removed to change the MWT in figure 11 from 85° to 42.5° is due to thermal mass. Values in the range of 12,000 to 15,000 B.t.u. for a change in MWT of 1° appear valid for rail cars. The value to be used for a car may be determined when performing the reverse heat flow test. If we determine the U value at conditions of 130° car interior and 75° ambient, the car should be placed in the 75° ambient with the doors open for a time sufficient to permit the mass of the car to stabilize at 75°. Forty-eight hours should be sufficient. Hourly records should be made of the electric power required to heat the car interior to 130° and steady-state conditions. The hourly U heat transmission loss is then subtracted from the hourly power input readings. The difference is the amount of heat used to change the MWT. This difference divided by the change in MWT will give the thermal mass value in B.t.u./°F.

Let us assume we have tested a car and find a value of $U = 150 \text{ B.t.u./hr.} \times ^\circ\text{F.}$ and 12,000 B.t.u./°F. for thermal mass value. A typical performance graph for such a car may be as shown in figure 12. The car inside temperature and temperature of the evaporator coil are shown on the horizontal scales while heat in B.t.u./hr. is shown on the vertical scale. Ambient temperature is 100° and condensor temperature is 117°. The total heat load on the refrigerating unit is composed of the heating effect of the blower plus body heat transmission. Shown is the heating effect of about 5,000 B.t.u./hr. for a 2 horsepower blower. Also shown is the heat transmission load, which varies from 0 at 100° to 1,500 at 0°. The total heat load is 20,000 B.t.u./hr. at 0°. To allow for loss in efficiency with age, let us assume that the refrigerating unit of the car when new has a heat removal capacity of 25,000 B.t.u./hr. at 0° inside car temperature. A curve may be plotted of refrigeration capacity versus car interior temperature by multiplying 25,000 by the following values:

<u>Car interior temp. °F.</u>	<u>Capacity B.t.u./hr.</u>
0	25,000 x 1
10	" x 1.36
20	" x 1.78
30	" x 2.22
40	" x 2.76
50	" x 3.37
60	" x 3.96

Extend the curve by the straight dotted line as shown. The values on the dotted line will be approximate. The resultant curve is typical for most refrigerating units.

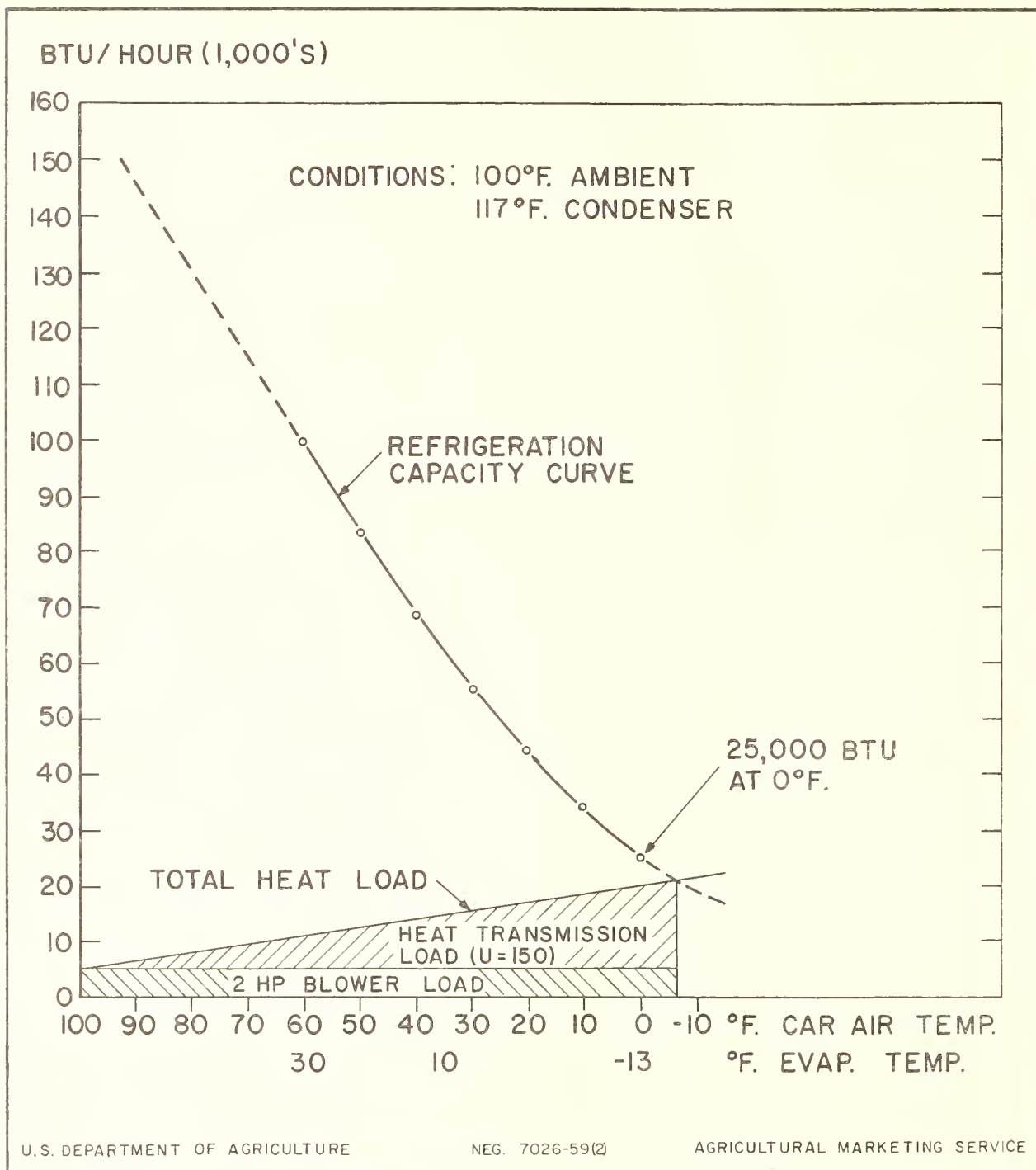


Figure 12.-- Typical performance graph of a refrigeration unit with a rating of 25,000 B.t.u./hr. at 0° F. inside car temperature.

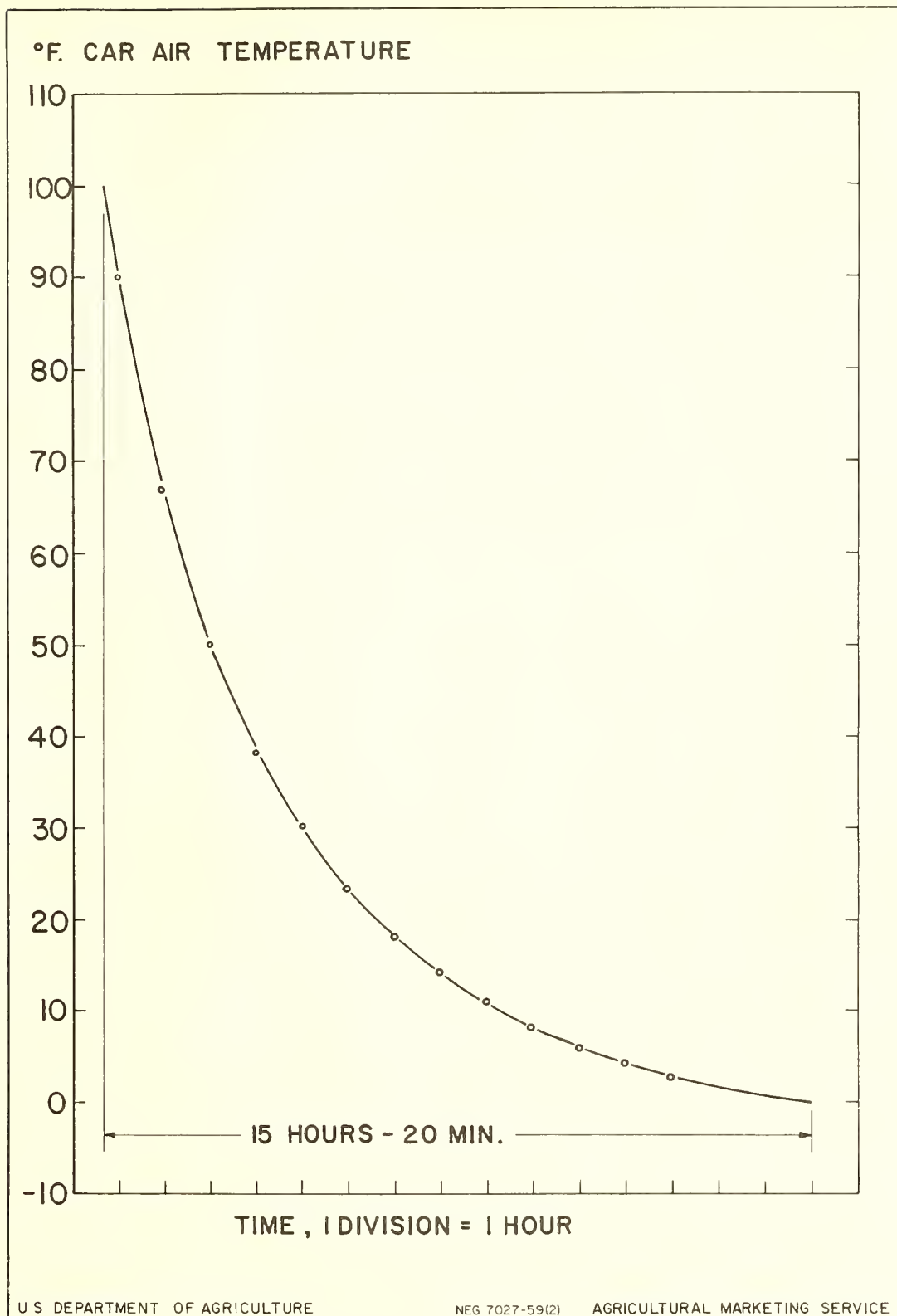


Figure 13.-- Pulldown curve for refrigeration unit shown in figure 12.

In figure 12, at a car temperature of 90° , the total refrigeration available is 145,000 B.t.u./hr. Subtracting from that figure the blower and heat transmission load of 7,000 B.t.u./hr., there remains 138,000 B.t.u./hr. excess to reduce the thermal mass. If 138,000 is divided by 12,000 (the thermal mass value) we obtain 11.5° , the number of degrees the mean wall temperature can be reduced in 1 hour. Since the MWT reduction is about $\frac{1}{2}$ the reduction of interior air temperature, the interior air temperature will be reduced to 23°

Figure 13 is a curve showing the pulldown curve for the refrigeration unit. The curve is formed by taking the difference of 23° from 90° , or 67° , and plotting the value of 67° at 1 hour from 90° . Again, by use of figure 12, the reduction in temperature below 67° for the next hour is calculated. The reduction in temperature for each succeeding hour is found in the same manner. The curve thus plotted shows a pulldown time of about 15 hours and 20 minutes. Figure 13 shows that the dotted portion of the curve in figure 12 would affect the time in figure 13 only about 1 hour.

To insure the performance shown in figure 13, a refrigeration unit should be selected that will approximate the curve shown in figure 12. If the expected temperature slip between car temperature and evaporator temperature is known (for example, evaporator temperature of -13° for car temperature of 0° , evaporator temperature of 10° for car temperature of 35° , etc.) a compressor, evaporator coil, and blower selection can be made.

Conclusions

The wide variations in performance shown by these tests indicate there is a need for a standard industrywide method of rating refrigerator cars. A standard test method should result eventually in improved car design and might afford a basis for better quality control and for the exchange of valuable information within the industry.

